H_2 and HD line emission from Pop III star formation

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Formation of Pop III (meta-free) Stars

Omukai and Nishi (1998)

Hydrodynamical Calculation

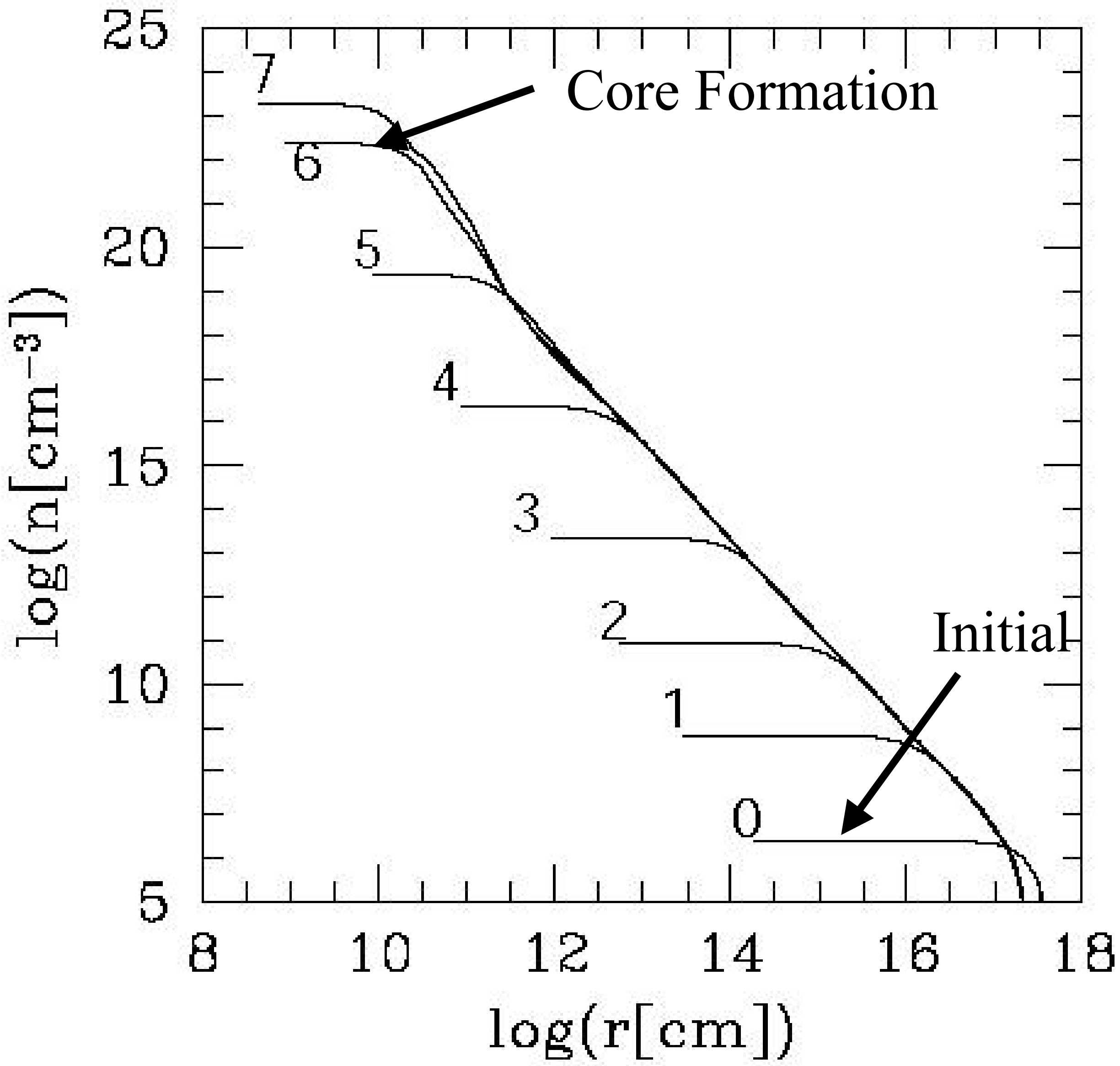
- Assume Spherical Symmetry
- Chemical Reactions
- Thermal Processes

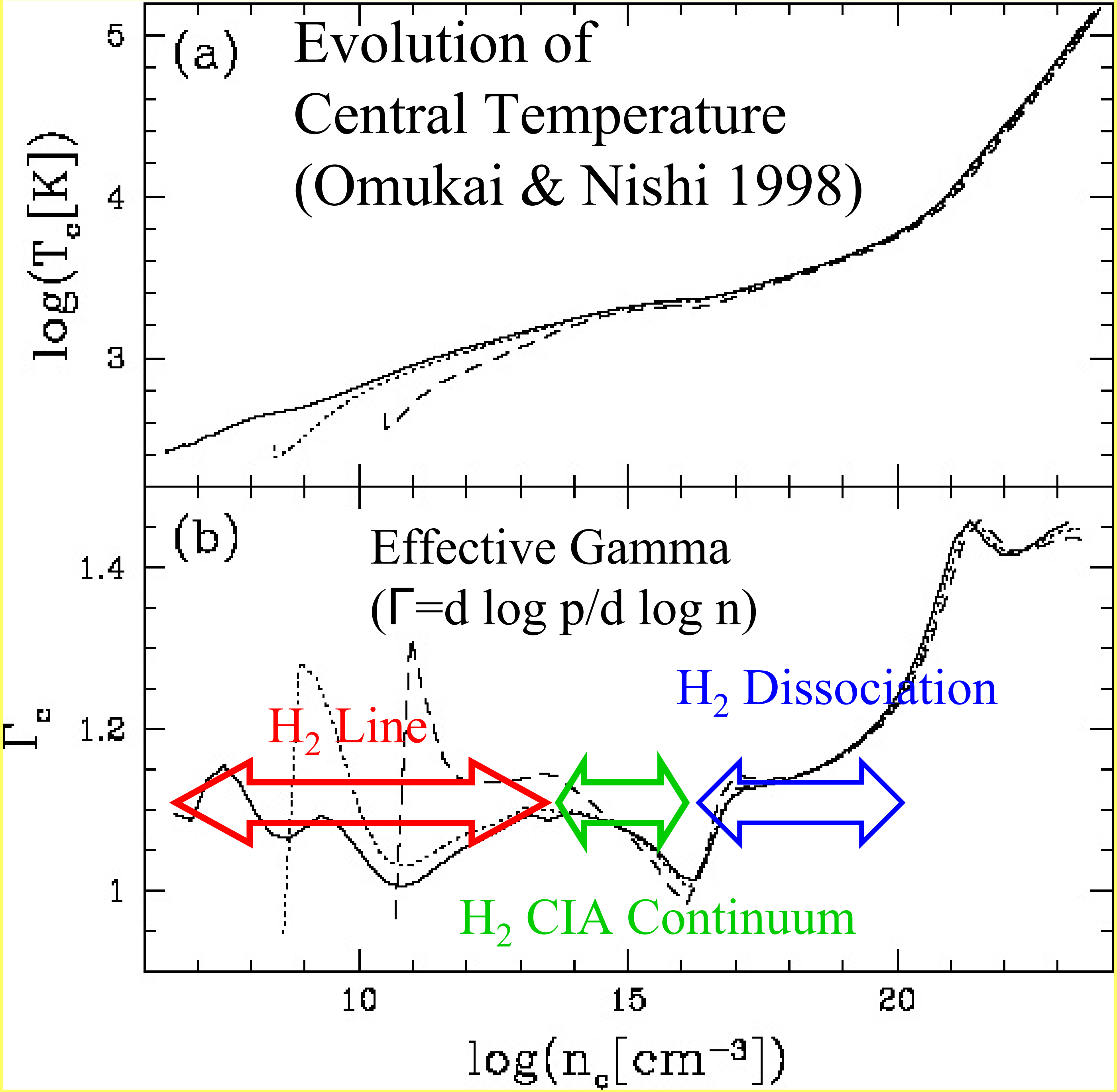
  (Radiative Transfer Including Line Profile)

Results

- Larson-Penston Similarity Solution like Collapse
- $M_*^{ini} \sim 5 \times 10^{-3}\ M_{sun}$
- $\dot{M} \sim 8 \times 10^{-2}\ M_{sun}\ yr^{-1}\ (t\ /\ 1yr)^{-0.27}$

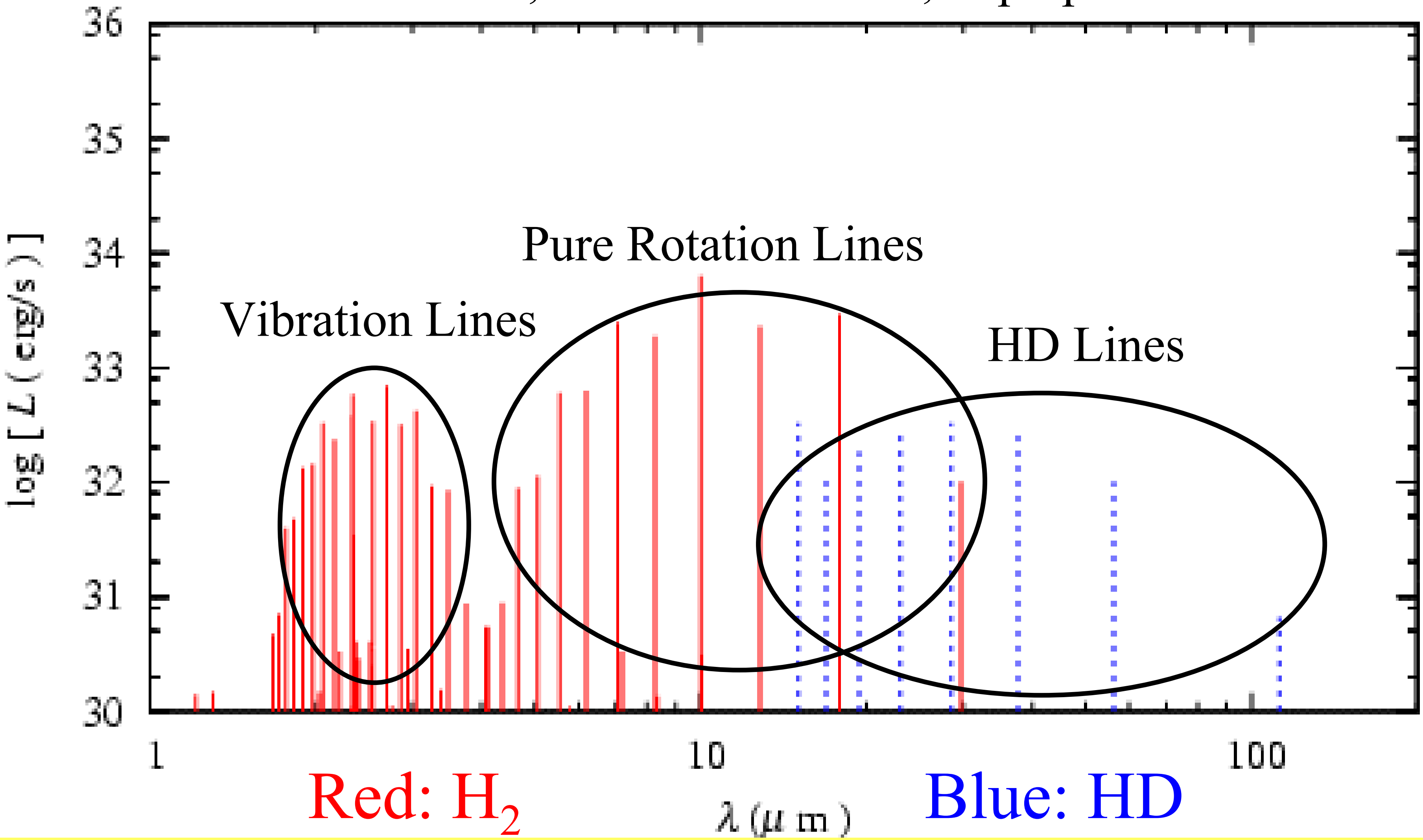
Evolution of Density Profile




(a)
Evolution of
Central Temperature
(Omukai & Nishi 1998)
log(T_c[K])
5
4
3
(b)
Effective Gamma
(Γ=d log p/d log n)
H2 Line
H2 Dissociation
H2 CIA Continuum
Γ_c
1.4
1.2
1
10
15
20
log(n_c[cm^-3])

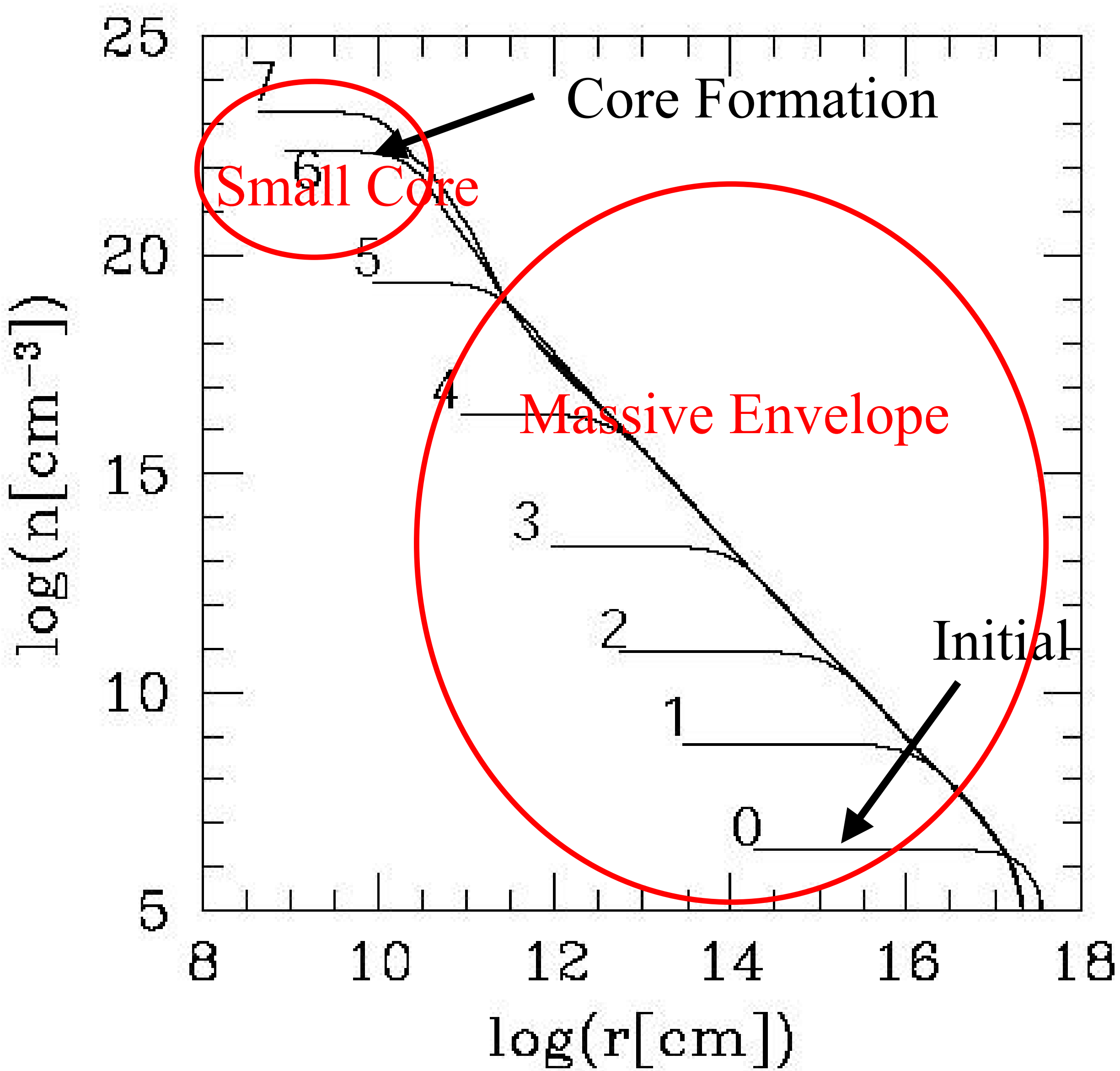
Time Averaged Line Luminosities

Mizusawa, Nishi and Omukai, in preparation



Li H lines are very weak

Evolution of Density Profile

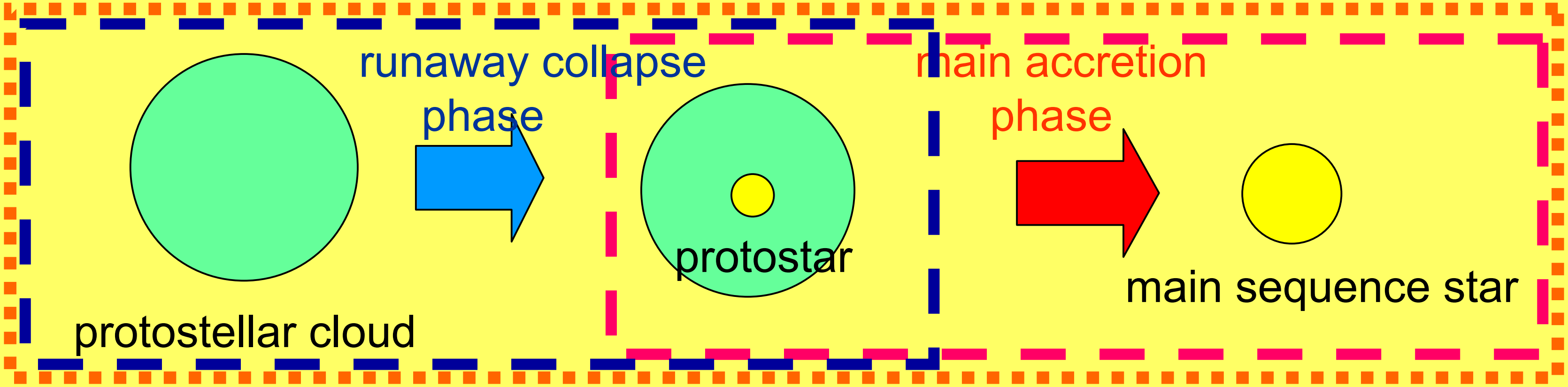


Purpose

We estimate the luminosities of H_2 lines, which can be characteristics of the first star formation process, and evaluate the detectability of H_2 lines.

The luminosities of H_2 lines for the runaway collapse phase → Ripamonti et al (2002) and Kamaya & Silk (2002)

Note that they highly overestimate the intensity for observer, since their d_L is wrong.



→ We calculate for both phases

Molecular line emission from metal free forming stars

Mizusawa, Nishi and Omukai (2004), PASJ in press

Initial Conditions

We adopt the typical values for the star-forming cores from Bromm et al.(2002).

The physical condition of fragments (protopstellar clouds)

$$M_J \sim 10^3 M_\odot$$

M_J : Jeans mass

$$n_{\mathbf{H}} = 10^4 (\mathbf{cm}^{-3}), T = 200(\mathbf{K}), y(\mathbf{H}_2) = 10^{-3}, y(\mathbf{e}^-) = 10^{-8}$$

$y(\mathrm{H_i}) = n(\mathrm{H}_i)/n(\mathrm{H})$: the concentration of the i-th species

$n(\mathrm{H})$: the number density of the hydrogen nucleus

Time Evolution of H_2 line emission

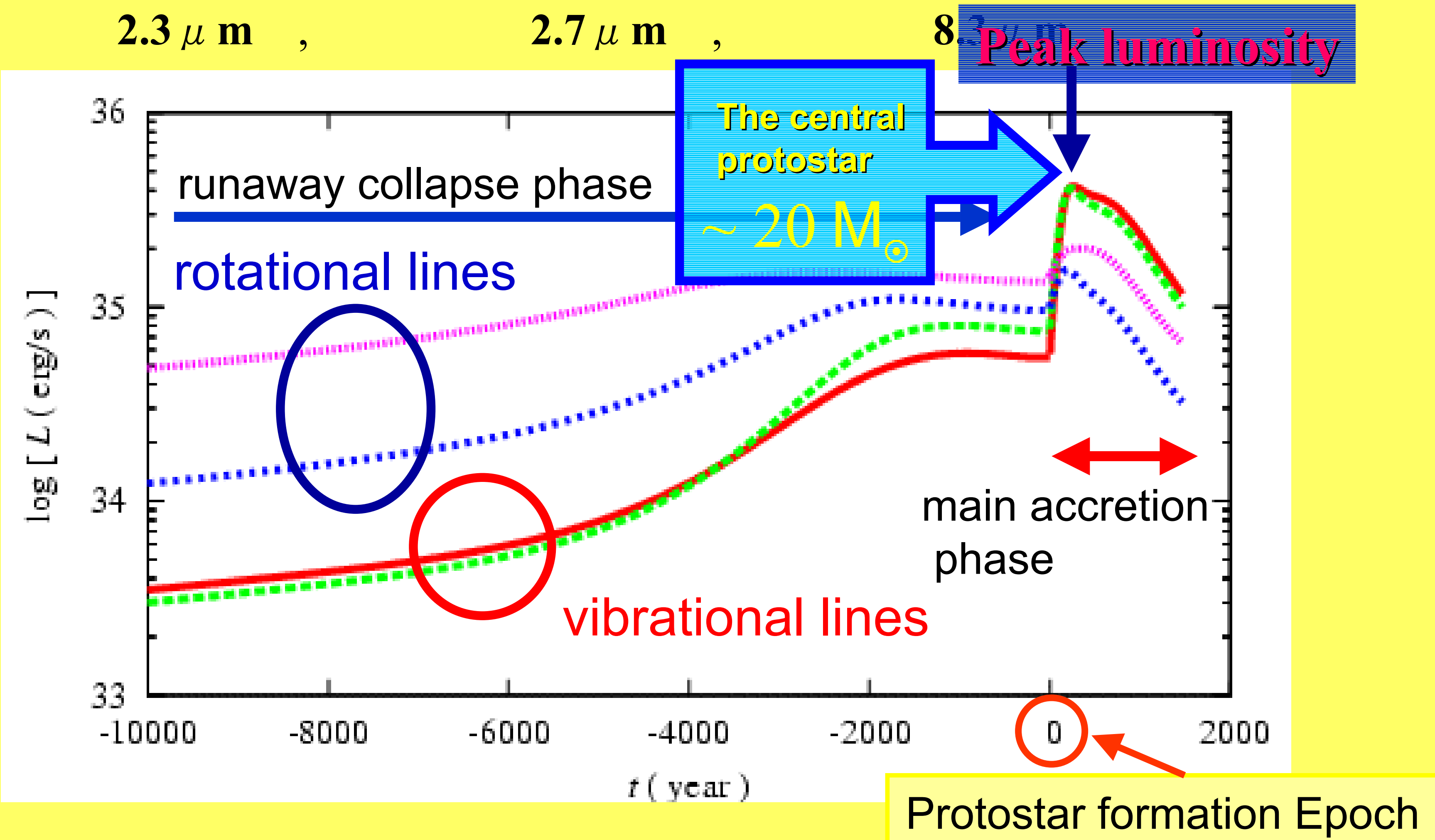
Pick up : four of the strongest H_2 lines

red : (1,1)→(0,1), **green**: (1,1)→(0,3), **blue** : (0,6)→(0,4), **purple** : (0,5)→(0,3)

rest frame:

2.3 μ m , 2.7 μ m , 8.3 μ m

10



Effects of Initial Conditions

- Bromm et al. (2002)

  $n_H = 10^4\ cm^{-3}$, $T=200K$, $y(H_2)=10^{-3}$
- Omukai and Nishi (1998)

  $n_H = 10^6\ cm^{-3}$, $T=250K$, $y(H_2)=10^{-3}$
- Palla et al. (1983)

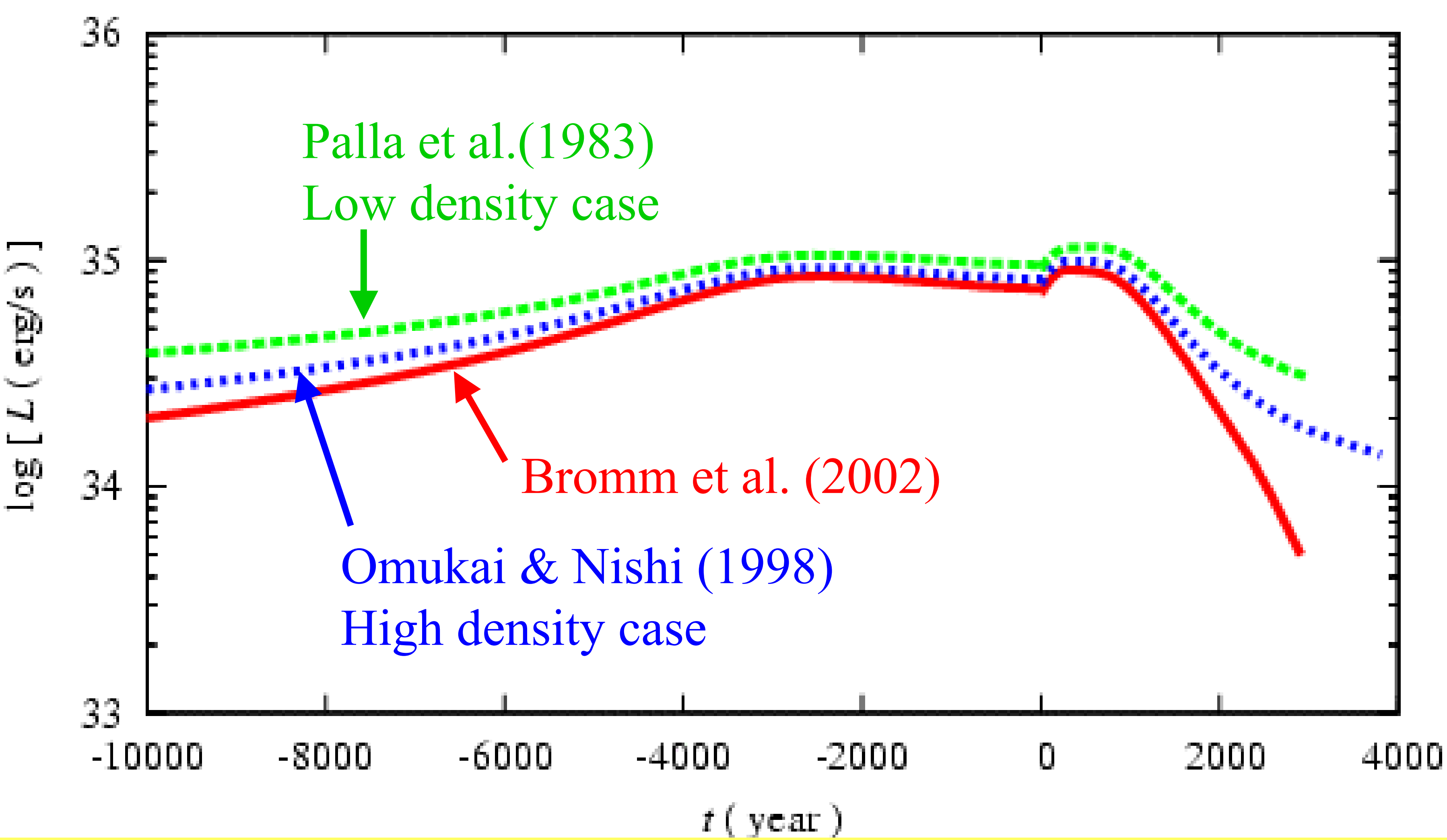
  $n_H = 2.9\ cm^{-3}$, $T=150K$, $y(H_2)=6.3\ \ 10^{-3}$

  (Low density case, massive envelope)

  Strong rotation lines

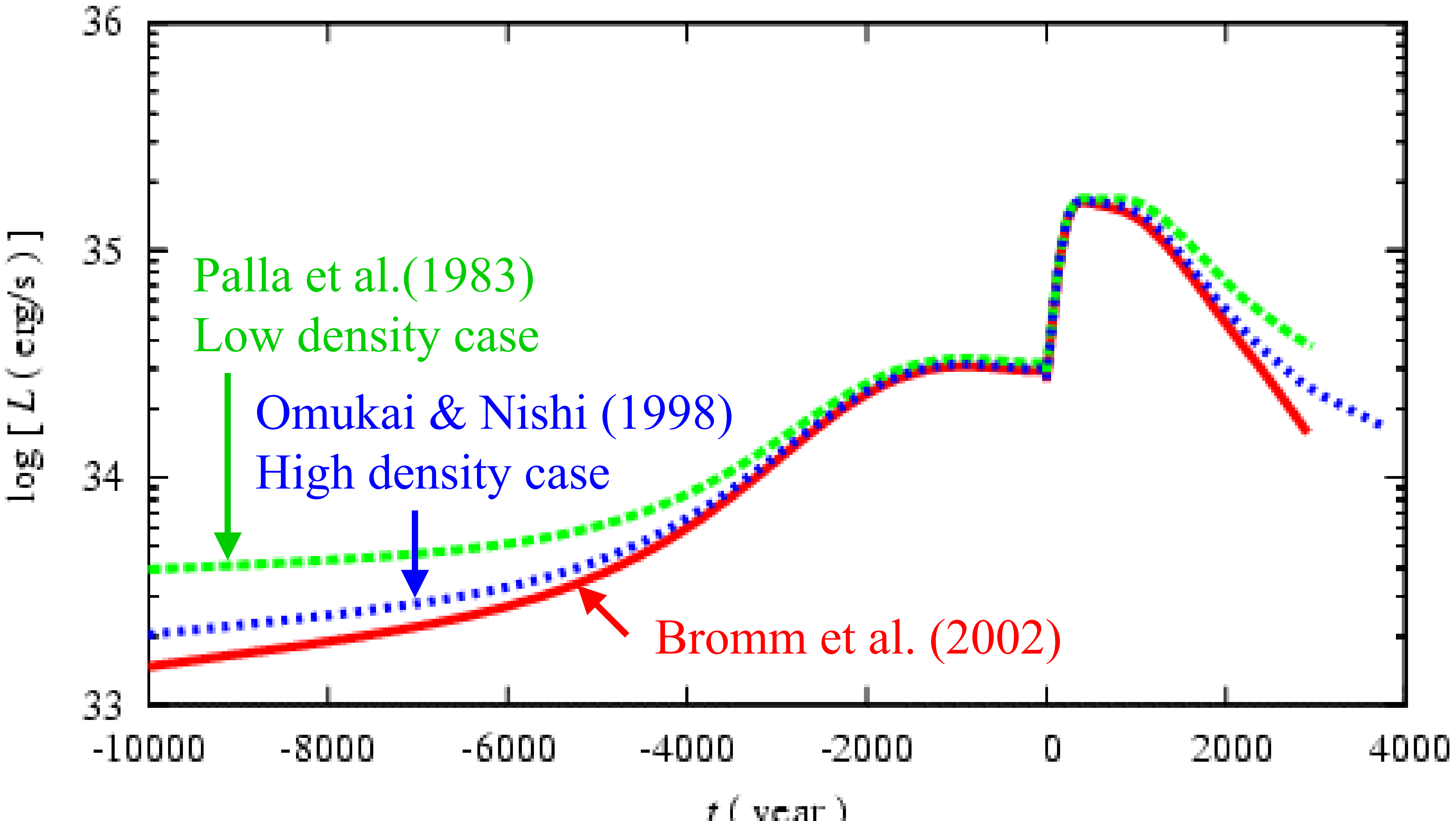
Time evolutions of rotational line luminosity

(0,5) ⟶ (0,3) (λ =10 μ)



Time evolutions of vibrational line luminosity

(1, 1) ⟶ (0,1) (λ =2.3 μ)



Detectability

For mid-infrared region ($\lambda \sim 40\,\mu\text{m}$),

a large cooled telescopes, e.g., **SPICA, SAFIR**, are **necessary.**

The line detection limit of SPICA is about $10^{-21}(\mathbf{W/m^2})$ in $\lambda \sim 40\,\mu\text{m}$

Limited by the high background of the zodiacal light

(private communication H.Matsuhara).

$(1,1) \rightarrow (0,1)$, rest frame: $\lambda = 2.34(\mu\text{m})$

redshifted $(1+z=20)$: $\lambda = 46.8\,(\mathbf{\mu m})$

$$F_{\text{peak}} = \frac{L_{peak}}{4\pi D_{z=19}^2} \sim 10^{-28.5}(\text{W}/\text{m}^2)$$

$D_{z=19}$: The luminosity distance to z=19

L_{peak}: The peak luminosity

more than 10^7 sources (z=19) → SPICA can observe.

Summary & Discussion

- We estimate
  the H_2 line luminosities from the metal free star formation processes.

- The luminosities of both **vibrational lines** and **rotational lines** become maximum value at **the main accretion phase**.

- For the runaway collapse phase, the strongest lines are **rotational lines**.
  For the main accretion phase, **vibrational lines** overwhelm them.
- For the peak, **vibratinal lines** are stronger than rotational lines.

rotational lines ----- low density region such as envelope of the protostellar clouds
vibrational lines ----- high density region such as final stage of star formation process
vibrational lines → **the strong evidence** of the first-generation star formation

For observation of the first-generation star,
vibrational lines are important.

If there exist $\geq 10^7$ sources @ $z \sim 19$,

SPICA can observe forming first-generation stars.

To exist 10^{7-8} sources is **difficult situation at early universe.**

- First Stars ($z \sim 19$),
detecting H_2 line emission by **SPICA** is highly improbable.

- @ low z, such as $z \sim 3$,
detecting it from Pop III stars by **SPICA** is maybe possible (SFR $\geq 30 M_{sun}$).

✓ To emit mainly in H_2 lines at high density (vibration line region), the metallicity in the pregalactic clouds $< \sim 10^{-4} Z_{\odot}$ (Omukai 2000).

Detection of H_2 vibrational lines ➡ metal free star formation

Strong evidence

More Possibilities

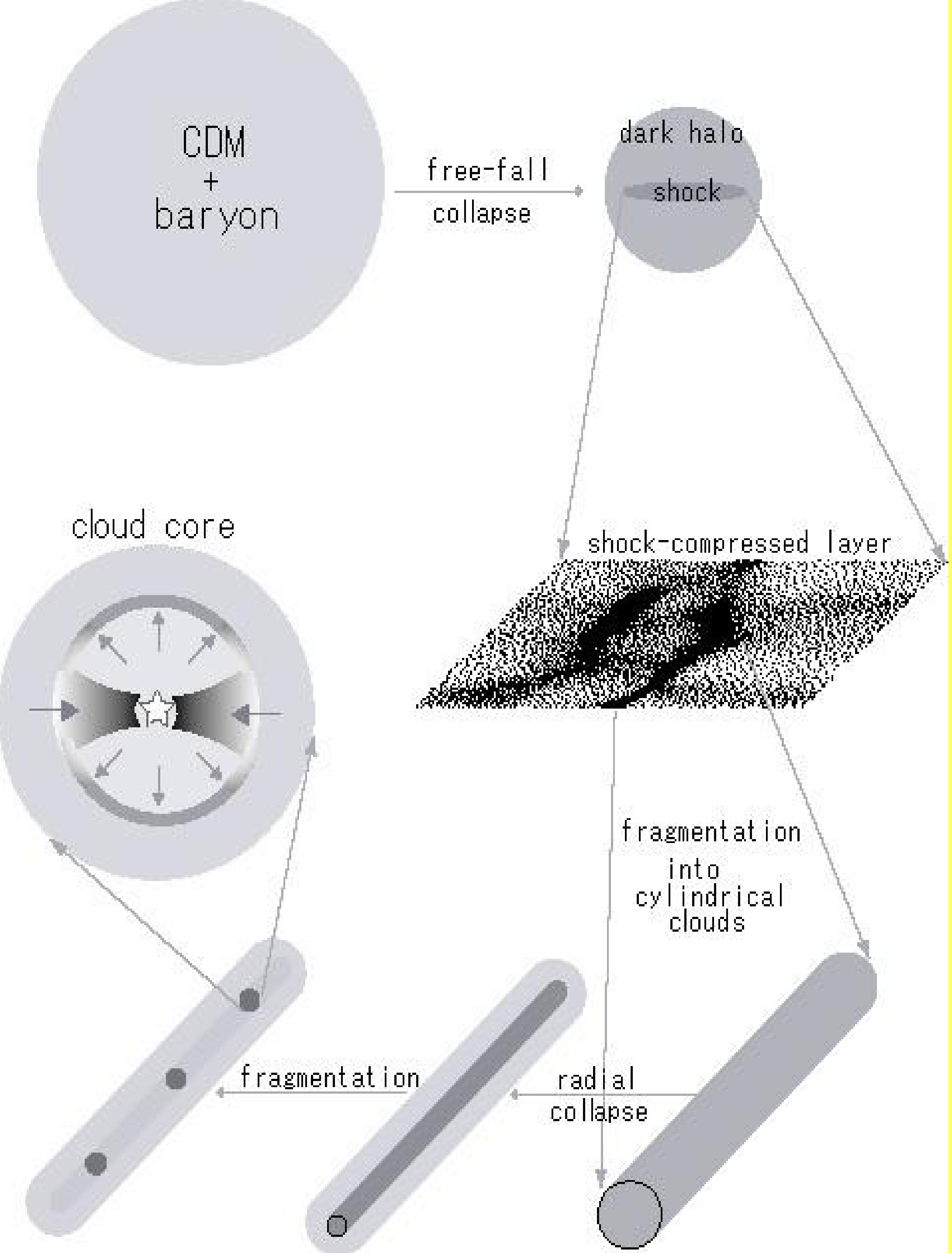
- Accretion phase is very complicated.

  Accretion disk

  $\longrightarrow$ Strong molecular emission

- Cylindrical Collapse

  Possibility of Effective H_2 formation



Scenario of Formation of Larger Objects

Gravitational Collapse of Proto Clouds

↓

Cooling and Formation of Disk like Clouds

↓

Fragment into Cylindrical Clouds

↓

Cylindrical Collapse

↓

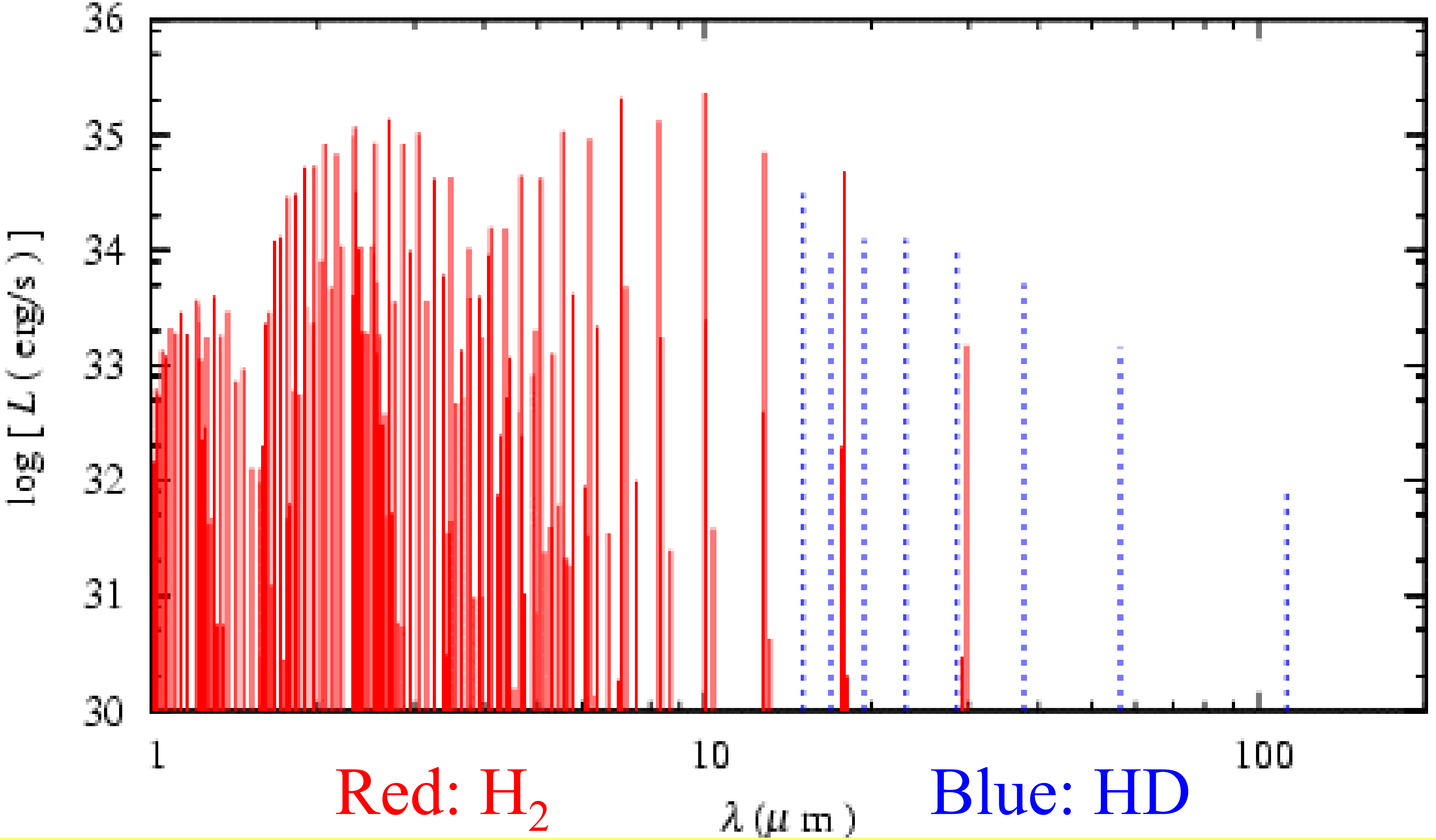
Fragmentation of Cylindrical Clouds

↓

Star Formation from the Core

Time Averaged Line Luminosities

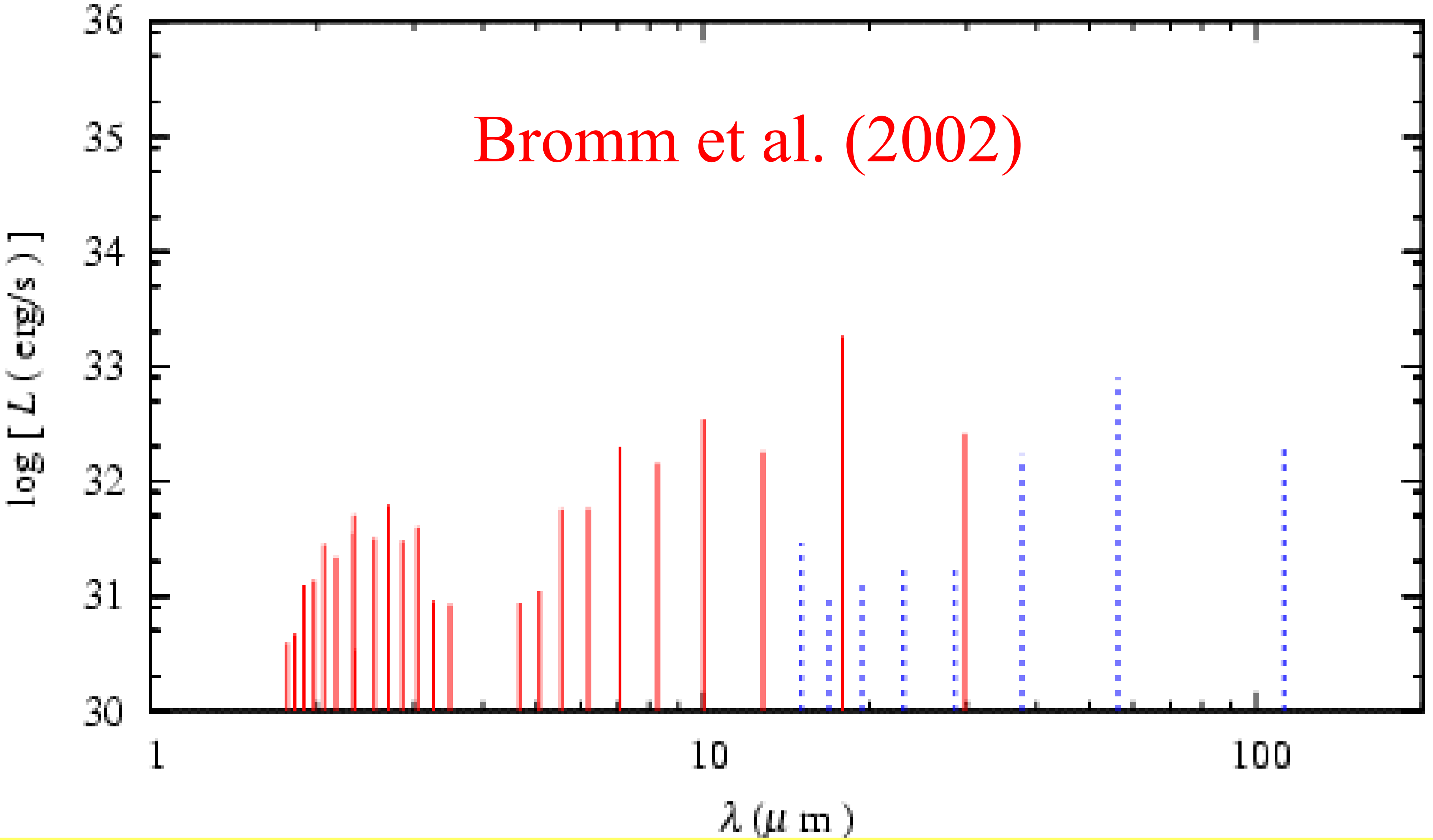
High density cylinder case (e.g. Nakamura & Umemura)



Red: H_2 Blue: HD

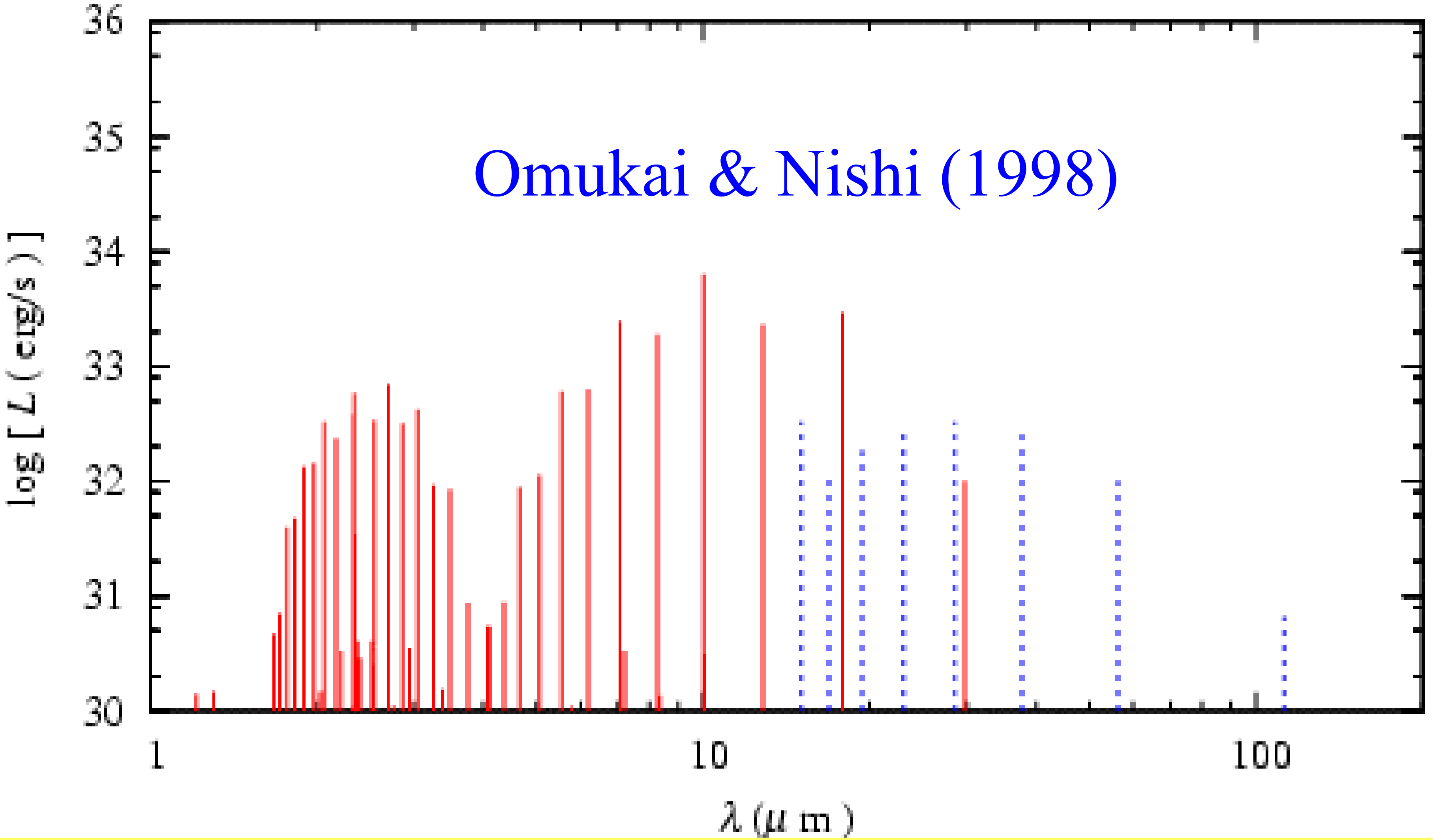
Total cylindrical cloud mass = $10^9 M_{sun}$

Time Averaged Line Luminosities



Red: H_2 Blue: HD

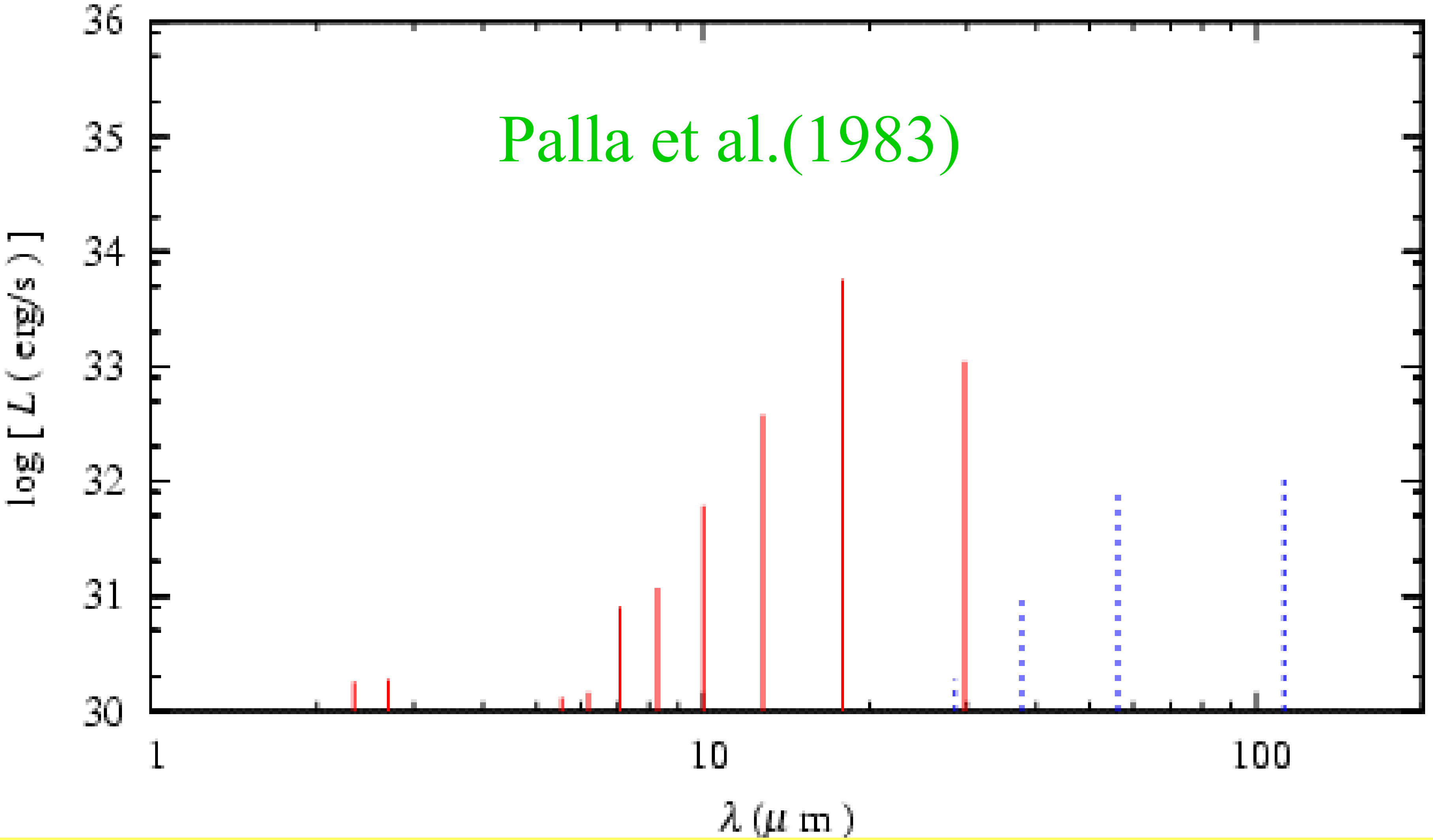
Time Averaged Line Luminosities



Red: H_2

Blue: HD

Time Averaged Line Luminosities



Red: H_2

Blue: HD